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## **DURIP 1999 Final Report**

**Contract # F49620-99-1-0221**  
**(April 1, 1999 to September 30, 2001)**

**"MOCVD Growth with in-situ characterization and femto-second two-color laser experiments  
for widegap III nitride materials and device development."**

**December 10, 2001**

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## Summary

This award provided funding for instrumentation that enhanced Oklahoma State University's research capabilities and strengthened our existing DoD-sponsored programs in the areas of semiconductor materials and device research, especially for MOCVD, MBE growth and characterizations for photonic applications. The instrumentation is applicable to a variety of semiconductors; however, our initial focus was on wide gap semiconductors, particularly group III-nitrides, GaN, AlN, InN and their alloys and heterostructures. The instrumentation is the Reflectance Difference Spectroscopy (RDS) system and separately tunable two-color Dual Frequency Femtosecond Laser Spectroscopy (DFLS) system. These systems interfaced to existing equipment procured with DoD funding, including a Thomas Swan MOCVD nitride growth reactor and a picosecond resolution streak camera.

The RDS system is portable and will be initially attached to our new MOCVD growth reactors for in-situ III-nitride growth monitoring and growth condition optimizations. A variety of AlGaIn and InGaIn based multi-layer device structures were grown for high temperature/power electronics and UV-blue photonic device applications such as AlGaIn UV photodetectors and UV laser diodes. Lateral epitaxial overgrowth (LEO) approach used on various substrates including Si, sapphire and Eagle-Picher ZnO. An array of microstructures will be grown by selective area overgrowth and processed for high power emitter and display applications. Additionally, specially designed AlGaIn and InGaIn multi quantum wells were grown to study fundamental electrical, optical, and structural material properties. The RDS system was also used for real-time semiconductor MOCVD surface studies and chemical reactions occurring with MOCVD precursors. Post-growth semiconductor characterizations are also planned with RDS. The DFLS system is based on all solid-state, nearly maintenance free lasers. The newly introduced 10W (largest capacity commercially available) diode laser pumped Nd:YAG laser (Millenia X) is very compact and portable, operating with a standard 110V wall plug-in. This Millenia X Nd:YAG laser pumps two Ti:Sapphire lasers, which are phase locked to each other to generate two separately tunable coherent femtosecond pulses. This state of the art DFLS system can be used for a variety of spectroscopic applications. Initial emphasis was on III-nitride research such as pump-probe time- and frequency-domain experiments for stimulated emission and lasing studies in AlGaIn and InGaIn-based structures. The DFLS system was also used for coherent transients and nonlinear optical studies of semiconductors pertinent to device applications such as switches, modulators and THz beam generators, as well as for elucidating fundamental processes occurring under high carrier density excitations. Because they are portable, femtosecond lasers can also be used for MOCVD and MBE in-situ growth studies.

## Acquired Equipment

Acquisition Date	Manufacturer	Description	
11/11/1999	Rhea Corporation	Detector, CCD System	\$5,110.00
11/11/1999	Ocean Optics	Spectrophotometer	\$3,003.00
2/21/2000	Products for Research	Heat Exchanger	\$4,120.90
2/21/2000	Hamamatsu Corp.	Photomultiplier Tube	\$2,445.70
3/27/2000	Melles Groit	Laser, Helium, Cadmium	\$9,268.40
3/28/2000	SPEX Industries	Module, High Voltage Power Supply	\$785.86
3/28/2000	SPEX Industries	Photon Counting Acquisition System	\$2,910.85
3/28/2000	SPEX Industries	Module, High Voltage Power Supply	\$785.86
7/20/2000	Technical Mfg Group	Table, Laboratory	\$2,490.00
9/1/2000	Thomas Swan	Susceptor, SIC Coated	\$1,600.00
12/7/2000	Laser Resale	Cabinets, Gas Used W/ZECL Accomodating	\$2,500.00
4/11/2001	Aixtron	MOCVD #2 (partially paid here)	\$132,532.25
		Other supporting materials for equipment	\$2,140.91
		Freight charges for shipping equipment	\$306.27
<b>Total</b>			<b><u>\$170,000.00</u></b>

## AFOSR-DURIP Report

Contract: #F49620-99-1-0221

**"MOCVD Growth with In-Situ Characterization and Femtosecond  
Two-color Laser Experiments for Widegap III-Nitride Materials  
and Device Development"**

March 31, 1999-June 30, 2001

## 1. MOCVD growth improvement

A custom made in-situ growth monitoring system was installed in a Thomas Swan GaN MOCVD system (GaN Epitor) and utilized for InGaN related material and device growth. Both IR interferometer system and blue reflection system have been applied for optimization of various growth parameters, which results in successful development blue LED structures.

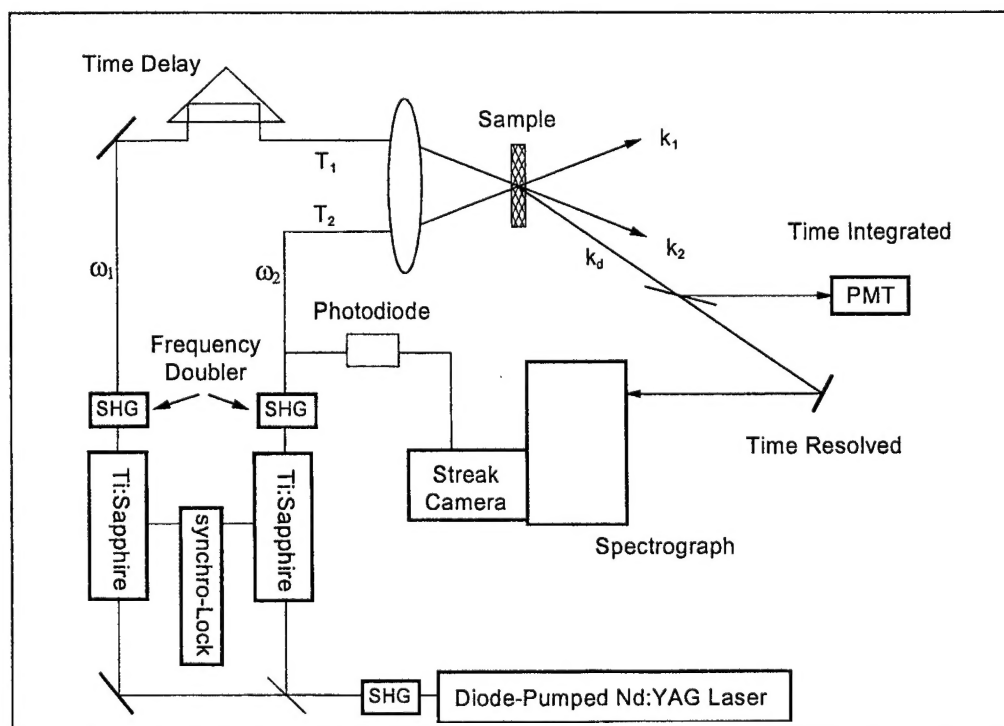
A new AIXTRON MOCVD system (HT200 RF-S) dedicated for the AlGaIn was purchased and installed. A commercially available in-situ monitoring and analysis equipment have been purchased with this MOCVD system, and will be utilized for the research on high Al composition AlGaIn growth and analysis of the growth mechanism.

We believe that commercial nitride MOCVD reactors are not as well-functioning as those for other materials such as GaAs, and that the MOCVD nitride reactor should continue to be modified as we go along.

Most importantly, it is widely believed that the defects in GaN related material dominantly affect the overall quality of GaN related materials and devices. Understanding of the growth mechanism and precise control of the growth parameters by the various in-situ monitoring and analysis system becomes more critical to the quality control and the development of the final devices.

## 2. Femtosecond laser system

We upgraded the dual frequency femtosecond lasers. The outline of the system is depicted below.



We modified and optimized our femtosecond laser-induced high carrier density setup for pump-probe experiment, as well as harmonic generation experiment over a wide wavelength range. With our femtosecond laser, we performed important experiments which result in many publications. The complicated theoretical interpretation of our experimental results was made by the Professor Y. C. Chang at the University of Illinois.

In addition, a visiting scientist from Russia collaborated in the use of our femtosecond laser system for harmonic generation in III-nitride materials and their heterostructures, a research area nearly unexplored yet. The results are now on interpretation and theoretical analysis.

Additional technical details can be found in the following documents.

A. Publication List.

B. Two articles from the Journal of Crystal Growth:

- 1) MOCVD growth, stimulated emission and time resolved PL studies of InGaN/(In)GaN MQWs: well and barrier thickness dependence.
- 2) Growth and in situ monitoring of GaN using IR interference effects.

C. A Ph.D. thesis in the Department of Physics: "" by Chan-Kyung Choi.

## RECENT PUBLICATIONS AND ABSTRACTS (1999-JUNE 2001)

### Publications (refereed):

"Femtosecond pump-probe spectroscopy and time-resolved photoluminescence of an InGaN/GaN double heterostructure," C. K. Choi, B. D. Little, Y. H. Kwon, J. B. Lam, J. J. Song, Y. C. Chang, S. Keller, U. K. Mishra, and S. P. DenBaars, *Phys. Rev. B* **63**, 195302 (2001).

"Time-resolved photoluminescence of InGaN/GaN multiple quantum well structures: effect of Si doping in the barriers," C. K. Choi, Y. H. Kwon, B. D. Little, G. H. Gainer, J. J. Song, Y. C. Chang, S. Keller, U. K. Mishra, and S. P. DenBaars, (submitted to *Phys. Rev. B* on 3/27/01).

"Ultrafast carrier dynamics in a highly excited GaN epilayer," C. K. Choi, Y. H. Kwon, J. S. Krasinski, G. H. Park, G. Setlur, J. J. Song, and Y. C. Chang, *Phys. Rev. B* **63**, 115315 (2001).

"MOCVD InGaN/GaN MQWs growth interruption effects," T. Sugahara, S. K. Shee, G. H. Park, S. J. Hwang, G. H. Gainer, J. J. Song, and S. Sakai, (submitted to *J. Cryst. Growth* on 3/22/01).

"Well thickness dependence of emission from GaN/AlGaIn separate confinement heterostructures," G. H. Gainer, Y. H. Kwon, J. B. Lam, S. Bidnyk, A. Kalashyan, J. J. Song, S. C. Choi and G. M. Yang, *Appl. Phys. Lett.* **78**, 3890 (2001).

"In<sub>2</sub>S<sub>3</sub> nanocolloids with excitonic emission: In<sub>2</sub>S<sub>3</sub> vs. CdS comparative study of optical and structural characteristics," D. K. Nagesha, X. Liang, A. A. Mamedov, G. Gainer, M. A. Eastman, M. Giersig, J. J. Song, T. Ni, N. A. Kotov, *The Journal of Physical Chemistry B* **105**, 7490 (2001).

"Optical properties and lasing in (In,Al)GaIn-based structures," S. Bidnyk, G. H. Gainer, S. K. Shee, J. B. Lam, B. D. Little, T. Sugahara, J. Krasinski, Y. H. Kwon, G. H. Park, S. J. Hwang, J. J. Song, G. E. Bulman, and H. S. Kong, *phys. stat. sol. (a)* **183**, 105 (2001).

"Comparative study of HVPE- and MOCVD-grown nitride structures for UV lasing application," J. B. Lam, G. H. Gainer, S. Bidnyk, Amal Elgawadi, G. H. Park, J. Krasinski, J. J. Song, D. V. Tsvetkov, and V. A. Dmitriev, *Mat. Res. Soc. Symp.* **639**, G6.4 (2001).

"Theoretical modeling of femtosecond pump-probe spectroscopy in GaN systems," Y. C. Chang, C. K. Choi, and J. J. Song, *The International Society for Optical Engineering (SPIE) Conf. Proc., Ultrafast Phenomena in Semiconductors V*, **4280** 58 (2001).

"Femtosecond pump-probe spectroscopy of a highly excited GaN epilayer," C. K. Choi, Y. H. Kwon, J. S. Krasinski, G. H. park, G. Setlur, J. J. Song, and Y. C. Chang, *The International Society for Optical Engineering (SPIE) Conf. Proc., Ultrafast Phenomena in Semiconductors V*, **4280** 89 (2001).

"Optical Properties of (Al)GaIn-Based Structures for Near- and Deep-Ultraviolet Emitters," S. Bidnyk, J. B. Lam, B. D. Little, G. H. Gainer, Y. H. Kwon, J. J. Song, G. E. Bulman, and H. S. Kong (submitted to *Jpn. J. Appl. Phys.* in 9/00).

"MOCVD growth, stimulated emission and time resolved PL studies of InGaN/(In)GaN MQWs: well and barrier thickness dependence," S. K. Shee, Y. H. Kwon, J. B. Lam, G. H. Gainer, G. H. Park, S. J. Hwang, B. D. Little, and J. J. Song, *J. Cryst. Growth* **221**, 373 (2000).

"Optical properties of (Al)GaN-based structures for near- and deep-ultraviolet emitters," S. Bidnyk, J. B. Lam, Y. H. Kwon, G. H. Gainer, B. D. Little, and J. J. Song, *Proc. Int. Workshop on Nitride Semiconductors (IWN2000)*, IPAP Conf. Series 1, 567 (2000).

"Linear and nonlinear optical properties of InGaN/GaN heterostructures," Y. H. Cho, T. J. Schmidt, S. Bidnyk, G. H. Gainer, J. J. Song, S. Keller, U. K. Mishra, and S. P. DenBaars, *Phys. Rev. B* **61**, 7571 (2000).

"Dynamics of anomalous optical transition in  $\text{Al}_x\text{Ga}_{1-x}\text{N}$  alloys," Y. H. Cho, G. H. Gainer, J. B. Lam, J. J. Song, *Phys. Rev. B* **61**, 7203 (2000).

"Study of gain mechanisms in AlGaIn in the temperature range of 30-300 K," J. B. Lam, S. Bidnyk, G. H. Gainer, B. D. Little, J. J. Song, and W. Yang, *Appl. Phys. Lett.* **77**, 4101 (2000).

"Time-resolved study of yellow and blue luminescence in Si- and Mg-doped GaN," Yong-Hwan Kwon, S. K. Shee, G. H. Gainer, G. H. Park, S. J. Hwang, and J. J. Song, *Appl. Phys. Lett.* **76**, 840 (2000).

"Study of gain mechanisms in  $\text{Al}_x\text{Ga}_{1-x}\text{N}$  in the temperature range of 30 to 300 K," J. B. Lam, S. Bidnyk, G. H. Gainer, B. D. Little, J. J. Song, and W. Yang, *Conference on Lasers and Electro-Optics (CLEO) 2000 Technical Digest*, CMG1 (2000).

"Microcavity-based semiconductor lasers for near- and deep-UV applications," S. Bidnyk, J. B. Lam, B. D. Little, Y. H. Kwon, J. J. Song, G. E. Bulman, and H. S. Kong, *Conference on Lasers and Electro-Optics (CLEO) 2000 Technical Digest*, CMG5 (2000).

"GaN/AlGaIn SCH UV semiconductor lasers: Effect of GaN well thickness on lasing efficiency," G. H. Gainer, Y. H. Kwon, J. B. Lam, A. Kalashyan, J. J. Song, S. C. Choi, and G. M. Yang, *Conference on Lasers and Electro-Optics (CLEO) 2000 Technical Digest*, CMG4 (2000).

"A comparative study of AlGaIn and GaN-based lasing structures for near- and deep-UV applications," S. Bidnyk, J. B. Lam, G. H. Gainer, B. D. Little, Y. H. Kwon, J. J. Song, G. E. Bulman, and H. S. Kong, *Mat. Res. Soc. Symp. Proc.* **T3.8**, 316 (2000).

"Comparison study of structural and optical properties of  $\text{In}_x\text{Ga}_{1-x}\text{N}/\text{GaN}$  quantum wells with different In compositions," Y. H. Kwon, G. H. Gainer, S. Bidnyk, Y. H. Cho, J. J. Song, M. Hansen, and S. P. DenBaars, *Mat. Res. Soc. Symp. Proc.* **595** and *MRS Internet J. Nitride Semicond. Res.* **5S1**, W12.7 (2000).

"Dynamics of anomalous temperature-induced emission shift in MOCVD-grown (Al, In)GaIn thin films," Y. H. Cho, G. H. Gainer, J. B. Lam, J. J. Song, W. Yang, and W. Jhe, *Mat. Res. Soc. Symp. Proc.* **595** and *MRS Internet J. Nitride Semicond. Res.* **5S1**, W11.57 (2000).

"Microstructure-based lasing in GaN/AlGa<sub>N</sub> separate confinement heterostructures," S. Bidnyk, J. B. Lam, B. D. Little, G. H. Gainer, Y. H. Kwon, J. J. Song, G. E. Bulman, and H. S. Kong, *Mat. Res. Soc. Symp. Proc.* **595**, W11.22 (1999); *MRS Internet J. Nitride Semicond. Res.* **5S1**, W11.22 (2000).

"Comparative study of near-threshold gain mechanisms in GaN epilayers and GaN/AlGa<sub>N</sub> separate confinement heterostructures," S. Bidnyk, J. B. Lam, B. D. Little, G. H. Gainer, Y. H. Kwon, J. J. Song, G. E. Bulman, and H. S. Kong, *The International Society for Optical Engineering (SPIE) Conf. Proc.* **3947**, 126 (2000).

"Mechanism of efficient ultraviolet lasing in GaN/AlGa<sub>N</sub> separate confinement heterostructures," S. Bidnyk, J. B. Lam, B. D. Little, Y. H. Kwon, J. J. Song, G. E. Bulman, H. S. Kong, and T. J. Schmidt, *Appl. Phys. Lett.* **75**, 3905 (1999).

"Structural and optical characteristics of In<sub>x</sub>Ga<sub>1-x</sub>N/GaN multiple quantum wells with different In compositions," Y. H. Kwon, G. H. Gainer, S. Bidnyk, Y. H. Cho, J. J. Song, M. Hansen, and S. P. DenBaars, *Appl. Phys. Lett.* **75**, 2545 (1999).

"A technique for evaluating optical confinement in GaN-based lasing structures," S. Bidnyk, B. D. Little, J. J. Song, and T. C. Schmidt, *Appl. Phys. Lett.* **75**, 2163 (1999).

"Room-temperature deep-ultraviolet-stimulated emission from Al<sub>x</sub>Ga<sub>1-x</sub>N thin films grown on sapphire," T. J. Schmidt, Y. H. Cho, J. J. Song, and W. Yang, *Appl. Phys. Lett.* **74**, 245 (1999).

"Near-threshold gain mechanisms in GaN thin films in the temperature range of 20-700 K," S. Bidnyk, T. J. Schmidt, B. D. Little, and J. J. Song, *Appl. Phys. Lett.* **74**, 1 (1999).

"High resolution x-ray analysis of pseudomorphic InGa<sub>N</sub>/GaN multiple quantum wells: Influence of Si doping concentration," Y. H. Cho, F. Fedler, R. J. Hauenstein, G. H. Park, J. J. Song, S. Keller, U. K. Mishra, and S. P. DenBaars, *J. Appl. Phys.* **85**, 3006 (1999).

"Stimulated emission in GaN thin films in the temperature range of 300-700 K," S. Bidnyk, B. D. Little, T. J. Schmidt, Y. H. Cho, J. Krasinski, J. J. Song, B. Goldenberg, W. Yang, W. G. Perry, M. D. Bremser, and R. F. Davis, *J. Appl. Phys.* **85**, 1792 (1999).

"Critical issues of localization in the development of InGa<sub>N</sub>/GaN laser diodes," S. Bidnyk, Y.-H. Cho, T. J. Schmidt, G. H. Gainer, J. J. Song, S. Keller, U. K. Mishra, S. P. DenBaars, W. Jhe, *Proceedings of Conference on Lasers and Electro-Optics (CLEO)/Pacific Rim '99, Technical Digest* **2**, 286 (1999).

"Comparison of spontaneous and stimulated emission from UV-blue photonic materials," B. D. Little, Y.-H. Cho, T. J. Schmidt, G. H. Gainer, J. B. Lam, J. J. Song, W. Yang, S. Keller, U. K. Mishra, S. P. DenBaars, W. Jhe, *Proceedings of Conference on Lasers and Electro-Optics (CLEO)/Pacific Rim '99, Technical Digest* **2**, 290 (1999).

"Optical emission characteristics of GaAs and GaN structures using low temperature near-field scanning optical spectroscopy," Y.-H. Cho, S. K. Eah, S. C. Hohng, D. S. Kim, G. M. Yang, J. J. Song, W. Jhe, *Proceedings of Conference on Lasers and Electro-Optics (CLEO)/Pacific Rim '99, Technical Digest* **3**, 999 (1999).

"Novel technique for evaluation of optical confinement in semiconductor laser structures through spatially and spectrally resolved emission spectra," S. Bidnyk, T. J. Schmidt, B. D. Little, J. Krasinski, J. J. Song, Conference on Lasers and Electro-Optics (CLEO) 1999 Technical Digest, CtuK52 (1999).

"Carrier recombination dynamics of  $\text{Al}_x\text{Ga}_{1-x}\text{N}$  epilayers grown by MOCVD," Y. H. Cho, G. H. Gainer, J. B. Lam, J. J. Song, W. Yang, and S. A. McPherson, Mat. Res. Soc. Symp. Proc. **572**, 457 (1999).

"Nondegenerate optical pump-probe spectroscopy of highly excited group III nitrides," T. J. Schmidt, J. J. Song, S. Keller, U. K. Mishra, S. P. DenBaars, and W. Yang, Mat. Res. Soc. Symp. Proc. **572**, 433 (1999).

"Study of near-threshold gain mechanisms in MOCVD-grown GaN epilayers and InGaN/GaN heterostructures," S. Bidnyk, T. J. Schmidt, B. D. Little, J. J. Song, Mat. Res. Soc. Symp. Proc. **572**, 439 (1999).

"Comparative study of emission from highly excited (In, Al) GaN thin films and heterostructures," B. D. Little, S. Bidnyk, T. J. Schmidt, J. B. Lam, Y. H. Kwon, J. J. Song, S. Keller, U. K. Mishra, S. P. DenBaars, and W. Yang, Mat. Res. Soc. Symp. Proc. **572**, 351 (1999).

"Carrier dynamics of abnormal temperature-dependent emission shift in MOCVD-grown InGaN epilayers and InGaN/GaN quantum wells," Y. H. Cho, B. D. Little, G. H. Gainer, J. J. Song, S. Keller, U. K. Mishra, and S. P. DenBaars, MRS Internet J. Nitride Semicond. Res. **4S1**, G2.4 (1999).

"Influence of Si-doping on carrier localization of MOCVD-grown InGaN/GaN multiple quantum wells," Y. H. Cho, T. J. Schmidt, S. Bidnyk, J. J. Song, S. Keller, U. K. Mishra, and S. P. DenBaars, MRS Internet J. Nitride Semicond. Res. **4S1**, G6.44 (1999).

"Room temperature laser action in laterally overgrown GaN pyramids on (111) silicon," S. Bidnyk, B. D. Little, Y. H. Cho, J. Krasinski, J. J. Song, W. Yang, and S. A. McPherson, MRS Internet J. Nitride Semicond. Res. **4S1**, G6.48 (1999).

"Amplification path length dependence studies of stimulated emission from optically pumped InGaN/GaN multiple quantum wells," T. J. Schmidt, S. Bidnyk, Y. H. Cho, A. J. Fischer, J. J. Song, S. Keller, U. K. Mishra, S. P. DenBaars, MRS Internet J. Nitride Semicond. Res. **4S1**, G6.54 (1999).

"Laser action in optically pumped GaN pyramids grown on (111) silicon by selective lateral overgrowth," S. Bidnyk, B. D. Little, Y. H. Cho, J. Krasinski, J. J. Song, W. Yang, S. A. McPherson, MRS Internet J. Nitride Semicond. Res. **4S1**, G6.48 (1999).

"Optical confinement and gain mechanisms in GaN-based lasing structures," S. Bidnyk, T. J. Schmidt, B. D. Little, and J. J. Song, 3<sup>rd</sup> Int. Conf. Nitride Semicond. (ICNS3) Proc. (1999).

"Optical nonlinearities in the band edge region of highly excited (In)GaN thin films studied via femtosecond and nanosecond optical pump-probe spectroscopy," T. J. Schmidt, A. J. Fischer, and J. J. Song, phys. stat. sol. **216**, 505 (1999).

"Effects of carrier localization on the optical characteristics of MOCVD-grown InGaN/GaN heterostructures," Y. H. Cho, T. J. Schmidt, A. J. Fischer, S. Bidnyk, G. H. Gainer, J. J. Song, S. Keller, U. K. Mishra, S. P. DenBaars, D. S. Kim, and W. Jhe, *phys. stat. sol.* **216**, 181 (1999).

"A comparison of the optical characteristics of AlGaIn, GaN, and InGaIn thin films," Y. H. Cho, T. J. Schmidt, G. H. Gainer, J. B. Lam, J. J. Song, S. Keller, U. K. Mishra, S. P. DenBaars, W. Yang, D. S. Kim, and W. Jhe, *phys. stat. sol.* **216**, 227 (1999).

"Evaluation of optical confinement in GaN-based lasing structures," S. Bidnyk, T. J. Schmidt, and J. J. Song, *phys. stat. sol.* **216**, 517 (1999).

"Stimulated emission and pump-probe studies of wide-gap nitrides for UV-blue photonic applications," J. J. Song, S. Bidnyk, and T. J. Schmidt, *The International Society for Optical Engineering (SPIE) Conf. Proc.* **3986-04**, (1999).

"Comparative study of near-threshold stimulated emission mechanisms in GaN epilayers and InGaIn/GaN multiquantum wells," S. Bidnyk, T. J. Schmidt, B. D. Little, J. Krasinski, J. J. Song, S. Keller, and S. P. DenBaars, *The International Society for Optical Engineering (SPIE) Conf. Proc.* **3625**, 68 (1999).

"Nonlinear optical spectroscopy of band tail states in highly excited InGaIn," T. J. Schmidt, Y. H. Cho, S. Bidnyk, J. J. Song, S. Keller, U. K. Mishra, and S. P. DenBaars, *The International Society for Optical Engineering (SPIE) Conf. Proc.* **3625**, 57 (1999).

"Ultrafast carrier dynamics in GaN epilayers studied by femtosecond pump-probe spectroscopy," A. J. Fischer, B. D. Little, T. J. Schmidt, C. K. Choi, J. J. Song, R. Horning, and B.L. Goldenberg, *The International Society for Optical Engineering (SPIE) Conf. Proc., Ultrafast Phenomena in Semiconductors III*, **3624**, 179 (1999).

"Time-resolved photoluminescence studies of GaIn, InGaIn, and AlGaIn grown by metalorganic chemical vapor deposition," Y. H. Cho, G. H. Gainer, J. J. Song, S. Keller, U. K. Mishra, S. P. DenBaars, W. Yang, and S. A. McPherson, *The International Society for Optical Engineering (SPIE) Conf. Proc., Ultrafast Phenomena in Semiconductors III*, **3624**, 283 (1999).

"Optical characteristics of group III nitride quantum structures," Y. H. Cho, W. Jhe, T. J. Schmidt, S. Bidnyk, G. H. Gainer, and J. J. Song, *Proceedings of the 3<sup>rd</sup> Korea-China Joint Workshop on Advanced Materials*, (invited), 351 (1999).

"Stimulated emission and pump-probe studies of wide-gap nitrides for UV-blue photonics applications," J.J. Song, S. Bidnyk, and T.J. Schmidt, *ISPA '99 Conf. Singapore*, (Nov. 29-Dec. 3, 1999).

"Comparison of spontaneous and stimulated emission from UV-blue photonics materials," B.D. Little, Y.H. Cho, T.J. Schmidt, G.H. Gainer, J.B. Lam, J.J. Song, W. Yang, S. Keller, U.K. Mishra, S.P. DenBaars, and W. Jhe, *Conference on Laser and Electro-Optics, CLEO/Pacific Rim '99, Technical Digest vol 2*, 290 (1999).

"Optical Emission characteristics of GaAs and GaIn structures using low temperature near-field scanning optical spectroscopy," Y.H. Cho, S.K. Eah, S.C. Hohng, D.S. Kim,

G.M. Yang, J.J. Song, and W. Jhe, Conference on Laser and Electro-Optics, CLEO/Pacific Rim '99, Technical Digest vol 3, 999 (1999).

"Nonlinear optical spectroscopy of highly excited InGaN/GaN multiple quantum well blue laser structures," T.J. Schmidt, S. Bidnyk, Y.H. Cho, G.H. Gainer, J.J. Song, 1999 CLEO Technical Digest Series, CtuU4, 202 (1999).

"Novel technique for evaluation of optical confinement in semiconductor laser structures through spatially and spectrally resolved emission spectra," S. Bidnyk, T.J. Schmidt, B.D. Little, J. Krasinski, J.J. Song, 1999 CLEO Technical Digest Series, CtuK52, 145 (1999).

## Abstracts

"Spatially resolved cathodoluminescence of laterally overgrown GaN pyramids on (111) Si substrate," Y. H. Cho, H.M. Kim, T.W. Kang, J.J. Song, and W. Yang, (accepted by the Fourth International Conference on Nitride Semiconductors).

"Femtosecond pump-probe spectroscopy of a highly excited GaN epilayer," C. K. Choi, Y. H. Kwon, J. S. Krasinski, G. H. Park, G. Setlur, J. J. Song, and Y. C. Chang, The International Society for Optical Engineering (SPIE) Photonics West 2001, 4280-10 (January 20-26, 2001).

"Theoretical modeling of femtosecond pump-probe spectroscopy in GaN systems," Y. C. Chang, C. K. Choi, and J. J. Song, The International Society for Optical Engineering (SPIE) Photonics West 2001, 4280-07 (January 20-26, 2001).

"Comparative study of HVPE- and MOCVD- grown laser structures for UV applications," J. B. Lam, S. Bidnyk, A. Elgawadi, G. H. Park, J. Krasinski, J. J. Song, D. V. Tsvetkov, V. A. Dmitriev, Mat. Res. Soc. Fall 2000, Boston, MA (November 27 - December 1, 2000).

"Optical properties and lasing in (In,Al)GaN-based structures," J. J. Song, S. Bidnyk, J. B. Lam, G. H. Gainer, and Y. H. Kwon, ISPSA 2000 (invited), Cheju, Korea (November 1 - 3, 2000).

"Absorption, emission, and carrier dynamics study of MOCVD-grown  $\text{Al}_x\text{Ga}_{1-x}\text{N}$  Alloys," Y. H. Cho, G. H. Gainer, J. B. Lam, J. J. Song, W. Yang, and T. W. Kang, ISPSA 2000, Cheju, Korea (November 1 - 3, 2000).

"Optical properties and lasing in (In,Al)GaN-based structures," S. Bidnyk, J. B. Lam, Y. H. Kwon, G. H. Gainer, S. K. Shee, G. H. Park, S. J. Hwang, B. D. Little, and J. J. Song, International Workshop on Physics of Light-matter Coupling in Nitrides, France (October 8 - 12, 2000).

"Optical properties of (Al)GaN-based structures for near- and deep-ultraviolet emitters," S. Bidnyk, J. B. Lam, Y. H. Kwon, G. H. Gainer, B. D. Little, and J. J. Song, Int. Workshop on Nitride Semicond. (IWN2000), TA2-3, Nagoya, Japan (September 24 - 27, 2000).

"MOCVD growth, stimulated emission and time resolved PL studies of InGaN/(In)GaN MQWs: well and barrier thickness dependence," S. K. Shee, Y. H. Kwon, J. B. Lam, G. H. Gainer, G. H. Park, S. J. Hwang, B. D. Little, J. J. Song, The Tenth International Conference on Metalorganic Vapor Phase Epitaxy (ICMOVPE-X), Sapporo, Japan (June 5 - June 9, 2000).

"Study of gain mechanisms in  $\text{Al}_x\text{Ga}_{1-x}\text{N}$  in the temperature range of 30 to 300 K," J. B. Lam, S. Bidnyk, G. H. Gainer, B. C. Little, J. J. Song, and W. Yang, Conference on Lasers and Electro-Optics (CLEO) 2000, CMG1, 76, San Francisco, CA (May 7 - 12, 2000).

"Microcavity-based semiconductor lasers for near- and deep-UV applications," S. Bidnyk, J. B. Lam, B. D. Little, Y. H. Kwon, J. J. Song, G. E. Bulman, and H. S. Kong,

Conference on Lasers and Electro-Optics (CLEO) 2000, CMG5, 78, San Francisco, CA (May 7 - 12, 2000).

"GaN/AlGaIn SCH UV semiconductor lasers: Effect of GaN well thickness on lasing efficiency," G. H. Gainer, Y. H. Kwon, J. B. Lam, A. Kalashyan, J. J. Song, S. C. Choi and G. M. Yang, Conference on Lasers and Electro-Optics (CLEO) 2000, CMG4, San Francisco, CA (May 7 - 12, 2000).

"A comparative study of AlGaIn- and GaN-based lasing structures for near- and deep-UV applications," S. Bidnyk, J. B. Lam, B. D. Little, Y. H. Kwon, and J. J. Song, Mat. Res. Soc. Spring Meeting 2000, T3.8, 316, San Francisco, CA (April 24 - 28, 2000).

"Comparative study of gain mechanisms in GaN epilayers and GaN/AlGaIn separate confinement heterostructures," S. Bidnyk, J. B. Lam, B. D. Little, G. Gainer, J. J. Song, American Physical Society March Meeting, R17.10, 739, Minneapolis, MN (March 20-24, 2000).

"Study of stimulated emission in AlGaIn thin films in the temperature range of 30 K to 300 K," J. B. Lam, S. Bidnyk, G. Gainer, B. Little, J. J. Song, and W. Yang, American Physical Society March Meeting, R17.11, 740, Minneapolis, MN (March 20-24, 2000).

"Recent progress in the development of (Al, Ga)N lasing structures for near- and deep-ultraviolet emitters," S. Bidnyk, J. B. Lam, B. D. Little, and J. J. Song, Sixth Wide Bandgap III-Nitride Workshop, MP-1.4, Richmond, VA (March 12-15, 2000).

"Comparative study of near-threshold gain mechanisms in GaN epilayers and GaN/AlGaIn separate confinement heterostructures," S. Bidnyk, J. B. Lam, B. D. Little, G. H. Gainer, Y. H. Kwon, and J. J. Song, The International Society for Optical Engineering (SPIE) Photonics West 2000, 3947-24, 126, San Jose, CA (January 23-28, 2000).

"Dynamics of anomalous temperature-induced emission shift in MOCVD-grown (Al, In)GaIn thin films," Yong-Hoon Cho, G. H. Gainer, J. B. Lam, J. J. Song, W. Yang, and W. Jhe, Mat. Res. Soc. Fall 99, Boston, MA (November 29 - December 3, 1999).

"Mechanism of efficient ultraviolet lasing in a GaN/AlGaIn separate confinement heterostructure," S. Bidnyk, J. B. Lam, B. D. Little, G. H. Gainer, Y. H. Kwon, J. J. Song, G. E. Bulman, and H. S. Kong, Mat. Res. Soc. Fall 99, Boston, MA (November 29 - December 3, 1999).

"Comparison study of structural and optical properties of  $\text{In}_x\text{Ga}_{1-x}\text{N}/\text{GaN}$  quantum wells with different In compositions," Yong-Hwan Kwon, G. H. Gainer, S. Bidnyk, Y. H. Cho, J. J. Song, M. Hansen, and S. P. DenBaars, Mat. Res. Soc. Fall 99, Boston, MA (November 29 - December 3, 1999).

"Stimulated emission and pump-probe studies of wide-gap nitrides for UV-blue photonic applications," (invited), J. J. Song, S. Bidnyk, and T. J. Schmidt, Design, 3896-04, Fabrication and Characterization of Photonic Devices, International Symposium on Photonics and Applications (ISPA), Singapore (November 29 - December 3, 1999).

"Optical characteristics of group III nitride quantum structures," (invited), Yong-Hoon Cho and W. Jhe (Center for Near-field Atom-photon Technology and Department of Physics, Seoul National University), T. J. Schmidt, S. Bidnyk, G. H. Gainer, and J. J. Song (Center for Laser and Photonics Research and Department of Physics, Oklahoma State University), 3<sup>rd</sup> Korea-China Joint Workshop on Advanced Materials, Cheju, Korea (August 23-27, 1999).

"Optical emission characteristics of GaAs and GaN based materials using near-field and far-field optics," (invited) Yong-Hoon Cho, Sang-Kee Eah, S. C. Hohng, D. S. Kim, W. Jhe (Seoul National University) T. J. Schmidt, S. Bidnyk, G. H. Gainer, and J. J. Song (Oklahoma State University), Korea Physics Society 99 Fall Meeting, I-05, Korea (October 15-16, 1999).

"Optical emission characteristics of GaAs and GaN structures using low temperature near-field scanning optical spectroscopy," Y.-H. Cho, S. K. Eah, S. C. Hohng, D. S. Kim, G. M. Yang, J. J. Song, W. Jhe, Conference on Lasers and Electro-Optics (CLEO)/Pacific Rim '99, P2.87, Seoul, Korea (August 30 - September 3, 1999).

"Femtosecond coherent and incoherent spectroscopies on GaN," Y. D. Jho, D. S. Kim, A. J. Fischer, J. J. Song, J. Kenrow, K. E. Sayed, and C. J. Stanton, Conference on Lasers and Electro-Optics (CLEO)/Pacific Rim '99, P1.53, Seoul, Korea (August 30 - September 3, 1999).

"Comparison of spontaneous and stimulated emission from UV-blue photonic materials," B. D. Little, Y.-H. Cho, T. J. Schmidt, G. H. Gainer, J. B. Lam, J. J. Song, W. Yang, S. Keller, U. K. Mishra, S. P. DenBaars, and W. Jhe, Conference on Lasers and Electro-Optics (CLEO)/Pacific Rim '99, WP5, Seoul, Korea (August 30 - September 3, 1999).

"Critical issues of localization in the development of InGaN/GaN laser diodes," S. Bidnyk, Y.-H. Cho, T. J. Schmidt, G. H. Gainer, J. J. Song, S. Keller, U. K. Mishra, S. P. DenBaars, and W. Jhe, Conference on Lasers and Electro-Optics (CLEO)/Pacific Rim '99, WP3, Seoul, Korea (August 30 - September 3, 1999).

"Optical confinement and gain mechanisms in GaN-based lasing structures," S. Bidnyk, T. J. Schmidt, B. D. Little, and J. J. Song, The Third International Conference on Nitride Semiconductors (ICNS3), We P092, 127, Montpellier, France (July 5-9, 1999).

"Effects of carrier localization on the optical characteristics of MOCVD-grown InGaN/GaN heterostructures," Y. H. Cho, T. J. Schmidt, A. J. Fischer, S. Bidnyk, G. H. Gainer, J. J. Song, S. Keller, U. K. Mishra, S. P. DenBaars, D. S. Kim, and W. Jhe, The Third International Conference on Nitride Semiconductors (ICNS3), We P093, Montpellier, France (July 5-9, 1999).

"A comparison of the optical characteristics of AlGaIn, GaN, and InGaIn thin films," Y. H. Cho, T. J. Schmidt, G. H. Gainer, J. B. Lam, J. J. Song, S. Keller, U. K. Mishra, S. P. DenBaars, W. Yang, D. S. Kim, and W. Jhe, The Third International Conference on Nitride Semiconductors (ICNS3), Montpellier, France (July 5-9, 1999).

"Optical nonlinearities in the band edge region of highly excited (Al, In)GaIn thin films studied via femtosecond and nanosecond optical pump-probe spectroscopy," T. J.

Schmidt, A. J. Fischer, J. B. Lam, and J. J. Song, The Third International Conference on Nitride Semiconductors (ICNS3), Montpellier, France (July 5-9, 1999).

"Evaluation of optical confinement in GaN-based lasing structures," S. Bidnyk, T. J. Schmidt, and J. J. Song, The Third International Conference on Nitride Semiconductors (ICNS3), Montpellier, France (July 5-9, 1999).

"Nondegenerate optical pump-probe spectroscopy of highly excited group III nitrides," T. J. Schmidt, J. J. Song, S. Keller, U. K. Mishra, S. P. DenBaars, and W. Yang, Mat. Res. Soc. Spring Meeting, San Francisco, CA (April 5-9, 1999).

"Carrier recombination dynamics of  $\text{Al}_x\text{Ga}_{1-x}\text{N}$  epilayers grown by MOCVD," Y. H. Cho, G. H. Gainer, J. B. Lam, J. J. Song, W. Yang, and S. A. McPherson, Mat. Res. Soc. Spring Meeting, San Francisco, CA (April 5-9, 1999).

"Study of near-threshold gain mechanisms in MOCVD-grown GaN epilayers and InGaN/GaN heterostructures," S. Bidnyk, T. J. Schmidt, B. D. Little, J. J. Song, Mat. Res. Soc. Spring Meeting, Y5.37, 382, San Francisco, CA (April 5-9, 1999).

"Comparative study of emission from highly excited (In, Al) GaN thin films and heterostructures," B. D. Little, S. Bidnyk, T. J. Schmidt, J. B. Lam, Y. H. Kwon, J. J. Song, S. Keller, U. K. Mishra, S. P. DenBaars, and W. Yang, Mat. Res. Soc. Spring Meeting, Y7.4, 388, San Francisco, CA (April 5-9, 1999).